2011

A Real Time Indoor Navigation and Monitoring System for Firefighters and Visually Impaired

Siddhesh R. Gandhi
University of Massachusetts Amherst

A REAL TIME INDOOR NAVIGATION AND MONITORING SYSTEM FOR FIREFIGHTERS AND VISUALLY IMPAIRED

A Thesis Presented

by

SIDDHESH RAJAN GANDHI

Submitted to the Graduate School of the

University of Massachusetts Amherst in partial fulfillment

Of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL AND COMPUTER ENGINEERING

May 2011

Department of Electrical and Computer Engineering

A REAL TIME INDOOR NAVIGATION AND MONITORING SYSTEM FOR FIREFIGHTERS AND VISUALLY IMPAIRED

A Thesis Presented

by

SIDDHESH RAJAN GANDHI

Approved as to style and content by:

____

Prof. Aura Ganz, Chair

____

Prof. C. Mani Krishna, Member

____

Prof. Russell Tessier, Member

____

Christopher V. Hollot, Department Head
Electrical and Computer Engineering

ACKNOWLEDGMENTS

I would like to thank my advisor, Prof. Aura Ganz for her encouragement, guidance and support throughout my graduate studies. I owe my deepest gratitude to her for giving me an opportunity to be part of Multimedia Networks Lab. It is an honor for me to work with Prof. Ganz.

I would like to thank Prof. Mani Krishna and Prof. Russell Tessier for being part of my thesis committee. I would also like to thank Carole Wilson for her insightful and valuable suggestions while working on this thesis topic.

I would also like to thank lab members of MNL (Srihari, Rohan, Russell, Xunyi, Hodei and Rajiv) for their help and support in performing the experiments indoors. Special thanks to James and Tushar for the help they provided throughout this thesis.

This thesis would not have been possible without the constant encouragement and support from my family and friends.

ABSTRACT

A REAL TIME INDOOR NAVIGATION AND MONITORING SYSTEM FOR FIREFIGHTERS AND VISUALLY IMPAIRED

MAY 2011

SIDDHESH RAJAN GANDHI, B.E., UNIVERSITY OF MUMBAI

M.S. E.C.E, UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Aura Ganz

There has been a widespread growth of technology in almost every facet of day to day life. But there are still important application areas in which technology advancements have not been implemented in a cost effective and user friendly manner. Such applications which we will address in this proposal include: 1) indoor localization and navigation of firefighters during rescue operations and 2) indoor localization and navigation for the blind and visually impaired population.

Firefighting is a dangerous job to perform as there can be several unexpected hazards while rescuing victims. Since the firefighters do not have any knowledge about the internal structure of the fire ridden building, they will not be able to find the location of the EXIT door, a fact that can prove to be fatal. We introduce an indoor location tracking and navigation system (FIREGUIDE) using RFID technology integrated with augmented reality. FIREGUIDE assists the firefighters to find the nearest exit location by providing the navigation instructions to the exits as well as an Augmented Reality view of the location and direction of the exits. The system also presents the Incident Commander the current firefighter's location superimposed on a map of the building

floor. We envision that the FIREGUIDE system will save a significant number of firefighters and victims' lives.

Blind or visually impaired people find it difficult to navigate independently in both outdoor and indoor environments. The outdoor navigation problem can be solved by using systems that have GPS support. But indoor navigation systems for the blind or visually impaired are still a challenge to conquer, given the requirements of low cost and user friendly operation. In order to enhance the perception of indoor and unfamiliar environments for the blind and visually-impaired, as well as to aid in their navigation through such environments, we propose a novel approach that provides context–aware navigation services. INSIGHT uses RFID (Radio Frequency Identification), and tagged spaces (audio landmarks), enabling a ubiquitous computing system with contextual awareness of its users while providing them persistent and context-aware information. We present INSIGHT system that supports a number of unique features such as: a) Low deployment and maintenance cost; b) Scalability, i.e. we can deploy the system in very large buildings; c) An on-demand system that does not overwhelm the user, as it offers small amounts of information on demand; and d) Portability and ease-of-use, i.e., the custom handheld device carried by the user is compact and instructions are received audibly.

CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

There has been considerable progress in the field of indoor navigation systems. Various technologies deployed for this purpose include UWB [3], WIFI [15] and IR [14]. UWB technology has very high accuracy but its very costly. IR technology requires the user to be in the line of sight of the IR receiver to function with high accuracy. So we still need to establish a tradeoff between the cost and the accuracy associated with the system. In this chapter, we will explain about: 1) i*ndoor localization and navigation of firefighters during rescue operations* (FIREGUIDE) and 2) *indoor localization* and *navigation* for *the blind and visually impaired population* (INSIGHT).

1.1 FIREGUIDE System

Firefighters put their own lives in danger to save innocent people trapped inside a building engulfed by fire. The mental state of firefighters during a rescue operation is not completely stable due to loss of visibility, urgent condition of victims and many other environmental factors. In such a situation, if the firefighters get confused about the location of the nearest exit door, then *lives of both firefighters and victims are jeopardized.*

To address these issues, we introduce the FIREGUIDE system which integrates indoor localization using passive RFID technology and Augmented Reality (AR) implemented on an Android-based Smartphone. The AR application displays the direction of EXITs relative to the firefighter as well as their distance from the firefighter (see Figure 1.1). The firefighter points the Smartphone's camera in a specific direction and the FIREGUIDE application will overlay information about the Exit doors (Synthetic information) on top of a smoky camera feed, facilitating the detection of the Exit doors.

The firefighter will carry an Android Smartphone and a RFID glove. In the environment, we deploy passive RFID tags (R-tags) on the walls and along the baseboard. The system also includes a FIREGUIDE server that stores information about the building, receives real-time updates about the firefighter location through the phone and computes the directions to the closest exit. The server software also displays the firefighter location on the building map which can be viewed by both the firefighter and the incident commander/fire chief. It is evident that the FIREGUIDE system will save a significant number of firefighters and victims lives.

We envision that FIREGUIDE can be provided as a subscription service to the fire departments. For wide deployment of such a system, each commercial building will be required to deploy the proposed infrastructure and share the building blueprints and tag deployment with such a service provider.

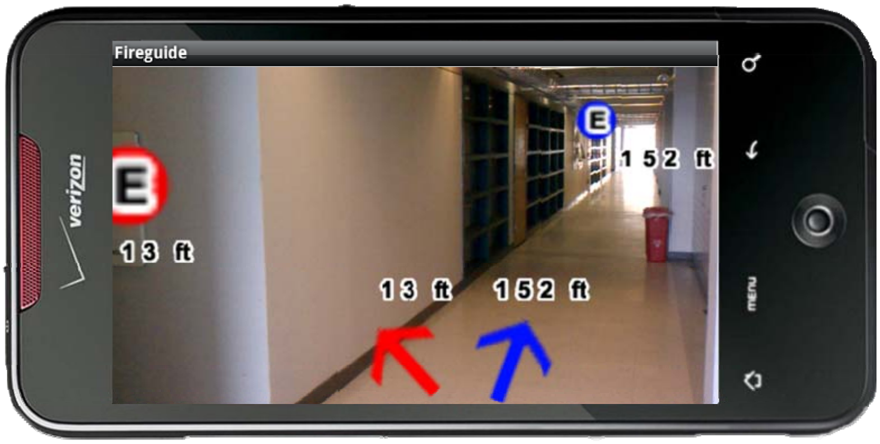


Fig. 1.1. Augmented Reality View

1.2 INSIGHT System

“Vision loss is taking an enormous toll in the U.S. and around the world. 161 million people worldwide have vision impairment and without intervention the number will almost double by 2020. Of the 161 million people, 37 million are blind and 124 million have low vision. Vision loss affects people of all ages. Every five seconds someone in the world goes blind. A child goes blind every minute. It's very likely that you or someone you love may face vision loss due to age-related macular degeneration, cataracts, diabetes-related eye disease, glaucoma or other eye disorders.” – These quotes by the Lighthouse International [1], a leading resource worldwide on vision impairment and vision rehabilitation, are enough to throw light on the importance of developing systems that aid the blind and visually-impaired.

Some organizations appoint a mobility trainer to guide blind or visually impaired people inside a building but this is not a feasible option when number of blind or visually impaired people increases. The use of a cane or a dog are other alternatives for navigation inside a building. A **conventional** indoor localization system can use a visual representation of various parts of building to guide a user who is (***not*** blind or visually impaired) to his destination. Guiding visually impaired person requires the system to use non-visual means of communication (e.g. audio feedback or some kind of vibration) to make a user aware of an obstacle. An indoor navigation system designed to facilitate navigation of blind or visually impaired people should take into consideration the exact needs of blind people (e.g. the user-friendly nature of the system, the amount of information to be given at a time, the accuracy of instructions, etc). We present INSIGHT which uses RFID sensors to guide visually impaired people inside a building.

The proposal is organized as follow: Chapter 2 provides a literature survey, a detailed overview of the system architecture, results and a hypothetical scenario of FIREGUIDE use. Chapter 3 gives information about the details of the INSIGHT system. Future work and conclusions are included in chapters 4 and 5.

CHAPTER 2

FIREGUIDE SYSTEM

In this chapter, we present the FIREGUIDE system in detail. Section 2.1 provides a literature review regarding current systems designed to help firefighters in distress. Section 2.2 introduces the concept of Augmented Reality, Android and OpenGL drawing tools. Section 2.3 describes various components of the system e.g. environment, client and server modules. Results are discussed in section 2.4 and a hypothetical use scenario is presented in section 2.5.

2.1 Literature Review

There are several systems that are deployed to help firefighters in distress. In [2] the system includes wireless motes which are contained in smoke detectors and EXIT signs. These motes broadcast their IDs while firefighters carry their own motes that listen for transmissions from other motes. Location tracking is based on signal strength measurements. Firefighter can see their location on a head-mounted display. An Incident Commander outside the building can also monitor the location of firefighters on a server. The “transfer motes” are deployed throughout the building to carry data collected by firefighters to the Incident Commander. The drawback of this approach is that the loss of “transfer motes” can disrupt system operation.

FINDER [3] uses Ultra Wide Band (UWB) technology to establish communication among firefighters. A firefighter in need of help sends UWB pulses which are received by other firefighters. Using this signal, an injured firefighter can be tracked. The disadvantage of this system is that there is no communication between the firefighters and the Incident Commanders so the Incident Commander is not able to locate the firefighters in distress.

FIREGUIDE uses multiple wireless technologies, (RFID and Wi-Fi/cellular) to collect information required to compute a firefighter's location and transmit this information to the incident commander. FIREGUIDE system includes two different applications to guide a firefighter towards the EXIT doors.

1. Shortest Route application
2. Augmented Reality application

Shortest Route application will show the shortest route to reach to the nearest EXIT door to the firefighter by taking into consideration the orientation of firefighter. Augmented Reality application will overlay EXIT door positions on top of a *live video camera feed* along with the direction and distance information. A user will be able to switch from one application to another with the press of a button. To the best of my knowledge there are no published systems that provide the location and distance of the EXIT doors using Augmented Reality. This information is very useful for the firefighter especially if he is in a smoky environment and/or loses his orientation.

2.2 Introduction to Augmented Reality and Drawing tools in Android and OpenGL platform

2.2.1. What is Augmented Reality?

There are two forms of presenting information about surroundings to a user, Virtual Reality (VR) and Augmented Reality (AR). Augmented Reality is a process of inserting synthetic information into the real world environment. The example of Augmented Reality can be overlaying information about various objects on top of a video feed. The information may be about the nature of an object where the camera is pointing (this will be useful in a museum to fetch information about various artifacts) or it could be about the twitter users within the radius of a few km (Layar app for Android). The main difference between VR and AR is the extent of insertion of the synthetic and real world information. In VR, real world information is immersed into a completely synthetic world, but in AR, synthetic information is inserted in a real world environment.

Augmented Reality applications provide certain challenges such as *tracking of the moving user*, the kind of *display technology* to be used and the *real time rendering* of the various information objects on top of a real environment. User tracking can be done in two ways. One way to determine the position of the user is to deploy sensors in the environment to track moving users. Another way to track the user is to deploy sensors on the device carried by the moving user, which then can determine their position by sensing the transmitters located in the environment. Display technology for AR applications has evolved by a great deal. Apart from Head Mounted Displays (HMD), Personal Digital Assistants (PDAs) can be used as a display medium for the user. A real time rendering challenge can be addressed with the use of GPUs and graphics libraries for embedded systems. A good example is the OpenGL libraries [17, 18] (OpenGL - Open Graphics Library).

Augmented Reality can be useful for emergency personnel as well as the general public. The general public can use such applications to find out information about nearest subway stations, twitter users, etc. Emergency personnel such as firefighters, rescue workers at a disaster scenario can also make use of AR to save the lives of people trapped in a building or at a disaster scene quicker than the traditional approach. FIREGUIDE uses Augmented Reality to display the location of Exit doors on top of a current camera feed to the firefighters. A smoky atmosphere can reduce the visibility for firefighters, thus making it difficult to search for the nearest Exit door on a particular floor. FIREGUIDE will overlay information about the Exit doors (Synthetic information) on top of a smoky camera feed, facilitating the detection of the nearest Exit doors.

2.2.2 Android platform and OpenGL introduction

Any Augmented Reality application will have following basic building blocks.

<table>
<tr><td colspan="3">User</td></tr>
<tr><td colspan="3">Application Interface (HCI Interface)</td></tr>
<tr><td>Tracking</td><td>Display</td><td>Real Time Rendering of Objects</td></tr>
</table>

Fig.2.1. Basic Layers of Augmented Reality Applications [21]

Application interface provides a way to the user to interact with the application in an effective manner (E.g. Touch screen input). Android platform is well equipped to develop Augmented Reality applications. Different kind of sensors such as Accelerometer, Orientation sensor, Gyroscope and Temperature sensors are supported in the Android platform. A very high resolution camera provides ideal means of displaying synthetic objects with information overlaid on a live video feed. The java compatibility and the open source nature of the android platform have helped it to become the most popular and useful mobile platform in the current market. The Android platform also has a wide graphic support in the form of OpenGL java libraries, View [19] and SurfaceView [20] components of the android architecture.

Android View and SurfaceView are the basic components to draw various shapes and images on the screen. The choice between the use of View and SurfaceView depends on the requirement of the application. If an application requires less user interaction, then android View is preferred over SurfaceView but when it comes to interact with the user and draw various objects on the screen **quickly** (when there is a strict timing requirement between input and output), Android SurfaceView is preferred over the View component. The Best example of such application is the Gaming industry. Most of the games built on android platform use SurfaceView to display various objects.

OpenGL libraries are specially designed to be used for applications involving very high usage of graphics. OpenGL libraries provide APIs allowing the programmer to interact with the graphics hardware for 2D as well as 3D rendering of drawing objects. OpenGL APIs give a very good control over the Frames Per Second (FPS) parameter (Number of frames displayed on the screen per second) to increase the user interactivity of the application. FIREGUIDE system uses SurfaceView and OpenGL libraries to show the shortest route to reach the nearest EXIT door and implement the augmented reality feature respectively.

2.3 FIREGUIDE System Architecture

The FIREGUIDE system architecture is composed of the following components as shown in Figure 2.2:

1. *Environment* -Passive RFID tags (R-tags) deployed in the building
2. *User Device* – RFID glove and the Android based smartphone
3. *FIREGUIDE Server* – FIREGUIDE server stores the building layout, R-tag deployment locations, and communicates with the user device.

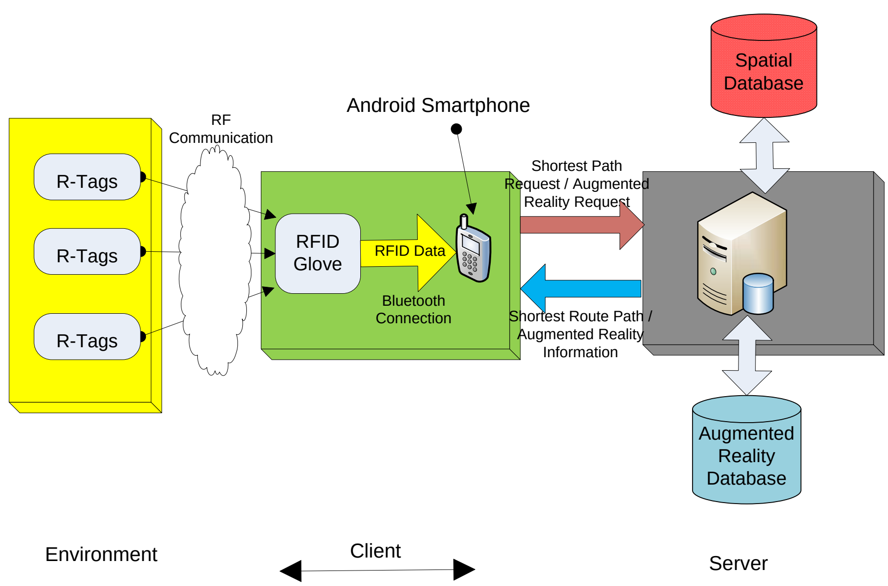


Figure 2.2. FIREGUIDE System Architecture

2.3.1. Environment

The environment includes passive RFID tags (R-tags) providing very accurate location information.

2.3.1.1. Passive RFID tag (R-tag)

R-tags (Fig. 2.3) are densely deployed in the building. They are located at each door of the building at a 4 ft height and at the baseboard level. Granularity was the main reason behind selecting this technology for FIREGUIDE. A proximity of 2-3 cm is required to transfer data from an RFID tag into the reader. Other reasons for selecting these R-tags were their cost and the fact that they do not need an active power source.

Figure 2.3 Passive RFID-tag

2.3.2. FIREGUIDE Client Module

This section describes the client software which includes the RFID glove and the Android Smartphone for visual representation.

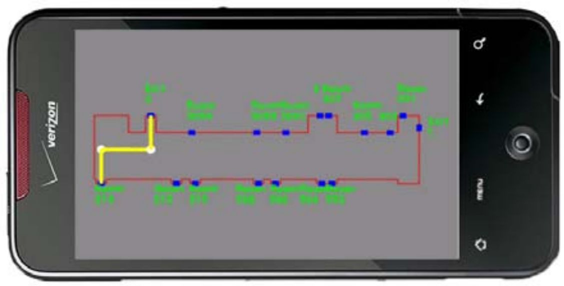
2.3.2.1. RFID Glove

The RFID Glove (Figures 2.4 (A) and (B)) allows the user free use of his hand as well as the ability to scan an R-tag. The R-tag is scanned by placing the palm on top of R-tag. The glove communicates the unique ID represented by an R-tag using Bluetooth technology to the Android Smartphone. There are 3 buttons (Button A, B, and C) provided on the glove. Each button has a different functionality implemented in the Android Smartphone to facilitate the navigation of the firefighter inside the building. When the firefighter scans an R-tag, the shortest route leading to the nearest Exit door is displayed on the Android Screen (see Figure 2.4 (C)). If this shortest route is infeasible to reach, then the firefighter has two options to find an alternative Exit door. The firefighter can press Button A to switch to the Augmented Reality view or the firefighter can press Button C which displays the shortest route path leading to the other Exit door. With the help of the shortest route map, the firefighter will know how to reach the nearest Exit door from his current location in the smoky environment (where visibility is almost zero). However, he will not have a complete picture of his surroundings. Button B is provided to resolve this issue. A picture of the surroundings of each R-tag will be stored in the Android phone. On pressing Button B, the firefighter will be presented a picture of his surrounding (with clear visibility). This picture will include the Left side view, Right side view and/or the view behind the firefighter. Figure 2.4 (D) shows the surroundings of Room 312 assuming the firefighter is facing towards the R-tag deployed in the corridor near Room 312.

(Figure 2.4 continues on the next page.)

(A).RFID Glove (back view) Scanning an R-Tag

(B). Front view of RFID Glove



(C).Shortest path GUI on Android Smartphone

(D). Picture of surroundings of Room 312

Figure.2.4. RFID glove and its functionalities

James Schafer has implemented RFID glove.

2.3.2.2 Android Smartphone Applications

Android Smartphone provides great features to build multiple applications in one single application. Android client module consists of Bluetooth module, Wi-Fi/Cellular module, Camera, Android basic Drawing APIs, OpenGL libraries, and shortest route and Augmented Reality applications. The overall block diagram of the Android client is shown in figure 2.5.

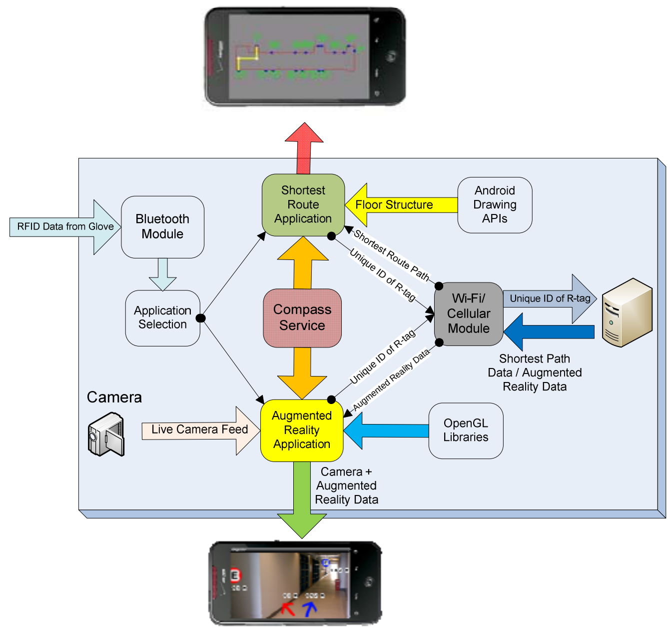


Figure.2.5. FIREGUIDE Client Architecture

The description of each module is as follows-

2.3.2.2.1. Bluetooth Module -

Bluetooth module is responsible for the successful exchange of RFID data from the RFID glove to the Android Smartphone. As soon as the main application starts, Bluetooth service is initiated as a background thread. This Bluetooth service will keep exchanging handshake signals with the RFID glove at regular intervals. Failure to receive handshake signals for a certain time interval indicates that the Bluetooth connection is broken. A new connection will be established after discovering that the previous connection was broken.

2.3.2.2.2. Wi-Fi/Cellular Module -

Wi-Fi/Cellular module takes care of exchange of data between the Android client and the FIREGUIDE server. Both applications (Shortest path and Augmented Reality Applications) access Wi-Fi module to fetch the required data from the server. If Wi-Fi radio is turned off in the middle of the application, Wi-Fi module will automatically detect this event and make sure the Wi-Fi connectivity is available for the applications to reach to the FIREGUIDE server.

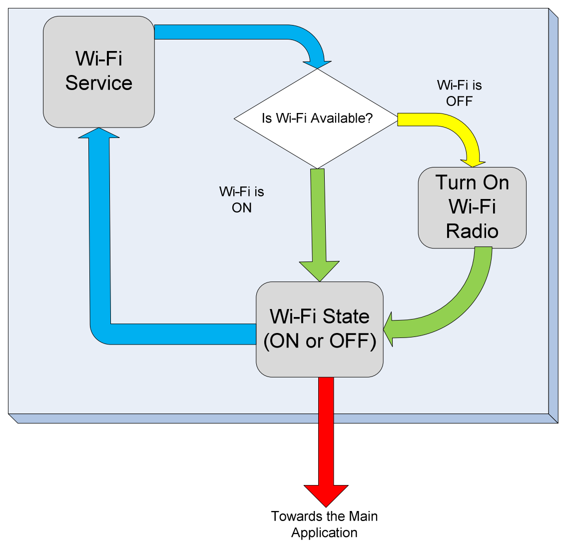


Figure 2.6. Wi-Fi Initialization Procedure

2.3.2.2.3. Compass Service

FIREGUIDE client uses orientation sensor to obtain the direction of the user. On starting up of any application of the FIREGUIDE client, a compass service is initiated. Compass Service is responsible for broadcasting the electronic compass readings at regular intervals. The readings range from 0 to 359 degrees with North corresponding to 0 degrees.

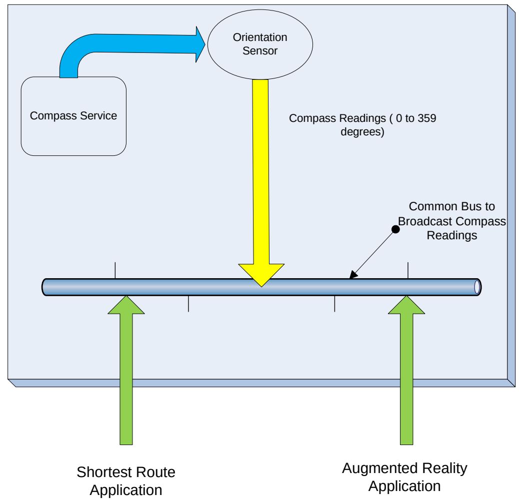


Figure 2.7 Compass Service

2.3.2.2.4. Application Selection Module

The user has an option of switching from one application to the other application just by pressing a button provided on the RFID glove. In the Following section, the Shortest Path and Augmented Reality applications will be explained in detail:

2.3.2.2.4.1 Shortest Path Application

Shortest Path Application is responsible for displaying the shortest route to the user from his location to the nearest EXIT door. It mainly consists of RFID processing module, Floor Blueprint variables, Drawing module, and Compass service. Floor blueprint variables include details of rooms and walls that exist on a building floor.

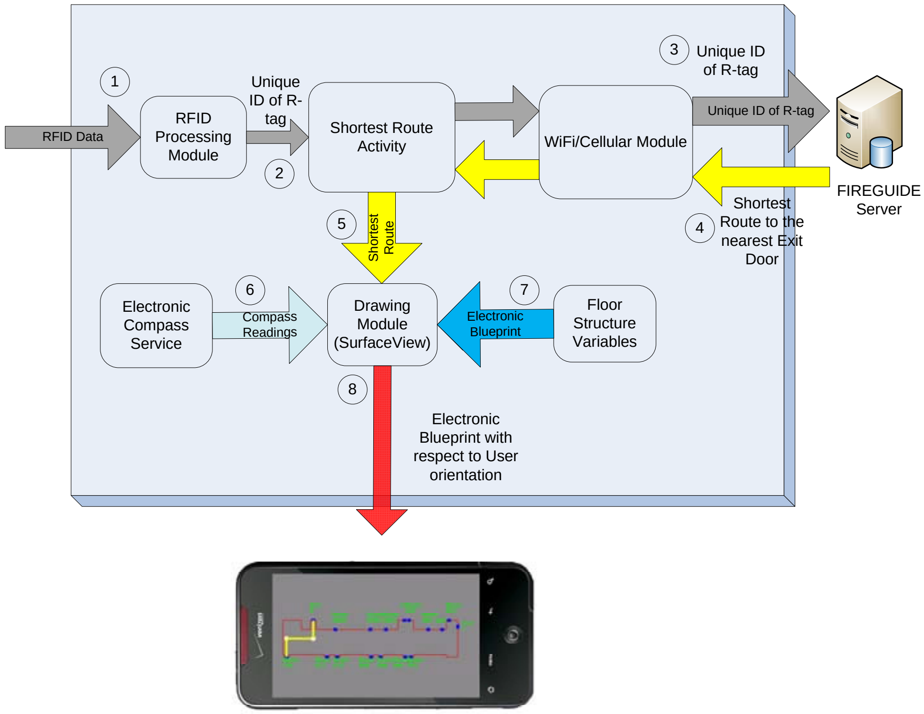


Fig.2.8. Shortest Route Path Application

2.3.2.2.4.1.1. RFID Processing Module

Every R-tag has a unique identifier (UID). On scanning an R-tag, the RFID processing module extracts the UID and sends it to the server over a wireless/Cellular network.

2.3.2.2.4.1.2. Floor Blueprint

The locations of each and every room and wall are stored in the form of a Text file in the Android platform. On startup of the Shortest Path Route application, these text files are parsed and stored in local data structures such as Arraylists. After this point, arraylists are accessed by the Drawing module in a much faster way to draw an electronic blueprint of the 3rd floor of the Knowles Engineering Building.

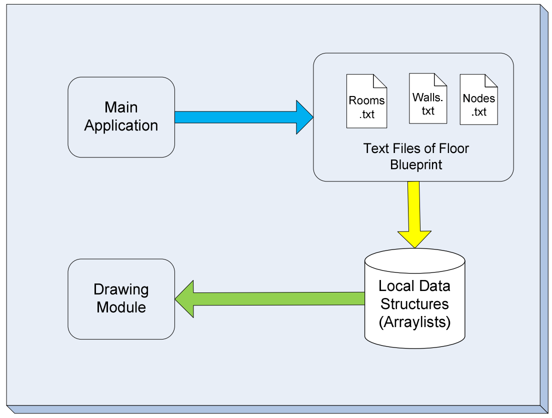
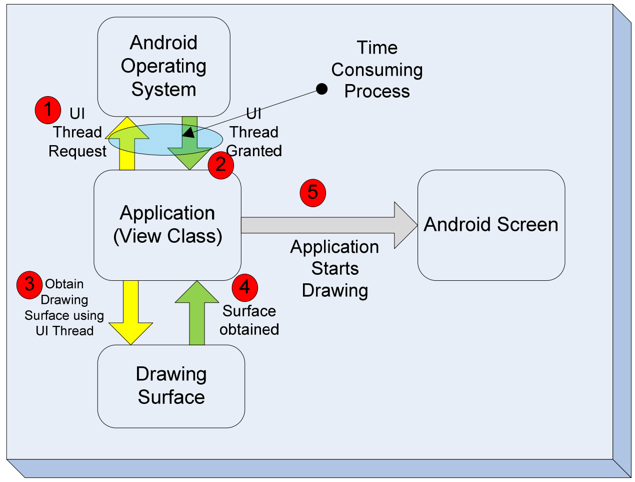


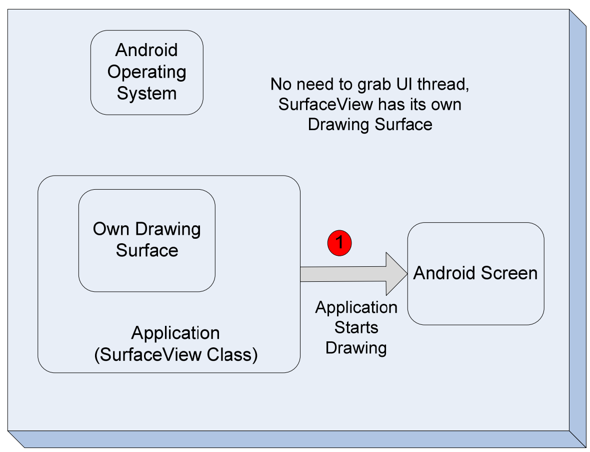
Figure. 2.9 Parsing of Floor Blueprint

2.3.2.2.4.1.3. Drawing Module

Under normal circumstances, android built in class viz. View is good enough to draw various 2D images on the screen. The Android Operating System maintains a User Interface (UI) thread to perform various activities related to the input (E.g. touch screen input) and output. Whenever the user gives command to draw a particular shape on the screen, View class waits until UI thread is made available to it by the android OS. This delay makes an application less responsive to the rapidly changing data. SurfaceView (another android class used for drawing images) has a capability to draw images rapidly without waiting for the UI thread to be made available by OS. Unlike View, Drawing using SurfaceView can be done by triggering a separate thread which makes SurfaceView an ideal choice for games and camera applications.



(1) Android View



(2). Android SurfaceView

Figure. 2.10 Comparison between View and SurfaceViews

Drawing module in the Shortest Path Route application uses SurfaceView to render drawing objects based on the compass readings. It accesses floor blueprint variables and then rotates the electronic blueprint depending on the compass readings.

<u>The flow of events in the Shortest Route Application is as follows:</u>

1) Firefighter scans an R-tag using the RFID glove. The data read by the glove is sent to the RFID processing module to extract the Unique Identifier (UID) from the rest of the data.

2) Unique ID is sent to the Wi-Fi/Cellular module which then sends it to the Server.

3) FIREGUIDE server locates the source and target node IDs of the required R-tag and executes the shortest path query.

4) The shortest path route is sent to the Android client.

5) Drawing Module gets the shortest path route.

6) Compass service keeps providing constant orientation readings to the Drawing module which then accesses Floor structure variables and draws the electronic floor blueprint.

7) When the shortest path route is obtained from the server, it is added on top of the electronic floor blueprint to display a complete picture of the corridor.

2.3.2.2.4.2 Augmented Reality Application:

The aim of the Augmented Reality (AR) application (See fig 2.11) is to help firefighters trapped in a building to quickly reach EXIT doors more effectively. Firefighter will be able to see EXIT doors (OpenGL objects) located on the same floor on top of a live video feed from the camera. The directions to reach EXIT doors will be given in the form of Arrows pointing in the direction of the EXIT doors.

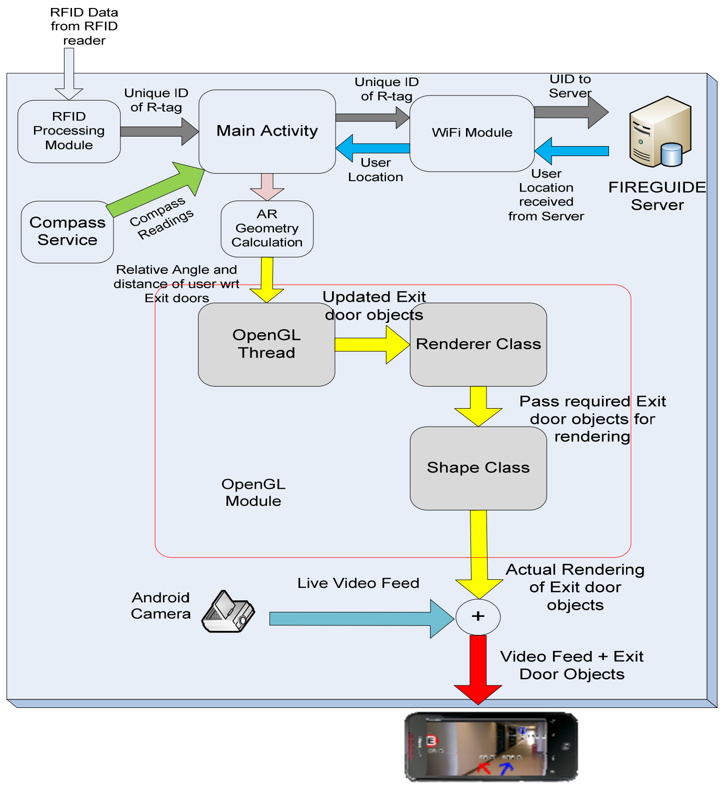


Fig 2.11. Augmented Reality Application

On startup, Exit door positions (x and y Co-ordinates) are obtained from the server and stored locally on the android platform. On scanning RFID tag, the location of the user is updated and the orientation of the user with respect to Exit door positions is calculated as discussed in the *AR geometry calculation section.*

2.3.2.2.4.2.1. Android Camera Video Feed Rendering

Android Smartphone (HTC Droid Incredible) has a very high resolution camera with APIs to control the parameters related to the Camera. The camera lifecycle is divided into 3 phases:

1) <u>Creation of the Surface for the camera</u> – In this phase, initial parameters such as preview size and orientation (Landscape or Portrait) of the Camera are set.

2) <u>Change of the Surface of the Camera</u> – When the user changes the orientation of the camera, then the camera parameters are changed to adjust to the new orientation. This happens when the Android Smartphone is tilted from either the horizontal (landscape) to vertical (portrait) position or vice versa.

3) <u>Camera Surface is destroyed</u>- As soon as the user quits the application related to the Camera, all the resources allocated for the camera are released and video feed is disconnected.

2.3.2.2.4.2.2. AR geometry calculation

In order to determine the direction of Exit doors with respect to the user, system requires two inputs from the user: orientation and location. Orientation sensor (Compass) in the Android platform provides the direction of the user, while the R-tag scanned by the glove provides the location of the user. The third floor (See fig 2.12) of the Knowles Engineering Building is used as the testbed for FIREGUIDE system.

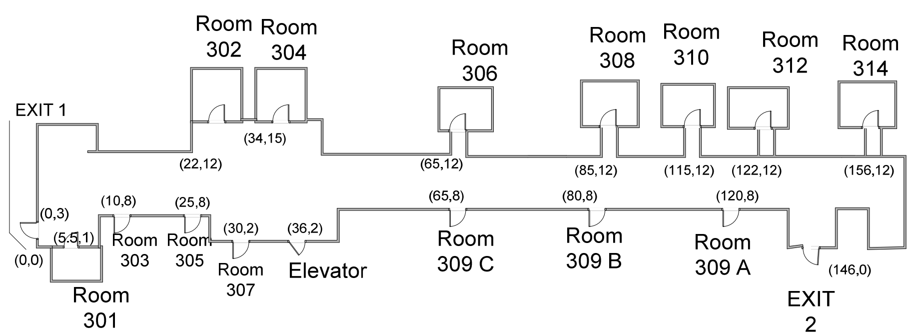


Fig.2.12. KEB 3rd floor corridor Co-ordinates

All the distances are measured in feet.

As shown Fig. 2.13,

Let x_1 and y_1 denote the x and y co-ordinates of the user location. Let x_2 and y_2 be the x and y co-ordinates of the Exit door location. *Distance r* = ***Sqrt*** $((x_1-x_2)^2 + (y_1 - y_2)^2)$

$\varphi = \sin^{-1}((x_1-x_2)/r)$ *degree.*

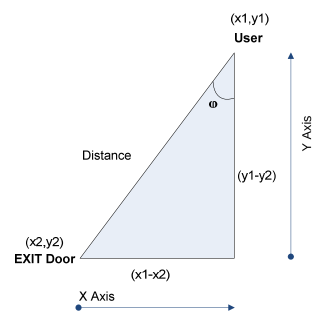
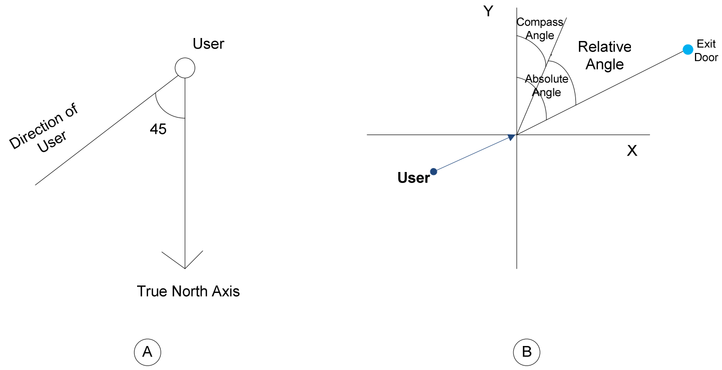


Fig.2.13. AR Geometry Calculations

To keep the angle calculations consistent with the compass readings obtained from the Android platform, if φ ***is*** negative, it is converted into a scale of 0 to 360 by adding 360 degrees to it (Figure 2.14 (A)). Once the absolute angle of the user with respect to the Exit door is obtained, the compass readings are processed to calculate the relative angle (Figure 2.14 (B)) of the user with regard to the EXIT door.



A) Compass orientation WRT true north axis, B) Relative angle calculation

Fig.2.14. Compass calculations

The most important aspect of the Augmented Reality application is to make it as responsive as possible to the orientation of the user. OpenGL libraries are best suited for 2D and 3D rendering of images. To increase the responsiveness of an application, a separate OpenGL thread is used to control the rendering of OpenGL objects on top of a camera feed. The Exit door objects (Fig. 2.15) are rendered on the screen *only if the relative angle between an Exit door object and the user is in the range of -45 to 45 degrees.* Renderer class (see Figure 2.11) checks for the above condition and passes OpenGL objects to the shape class to draw them on the screen. The arrows (see Figure 1.1) are also rendered on the screen to signify the direction that the firefighter should follow in order to reach an Exit door. These arrows are rotated on the screen with regard to the orientation of the firefighter.

Fig. 2.15. Exit Door Object

Exit door objects within a distance of 40 ft from the user are shown to the user by *magnifying their original size by a factor of 2.* This is a way of quickly making the user aware of the Exit doors which are closer to him on a particular floor. The distance of Exit doors is also printed below the Exit door objects (See fig 2.15) being shown on the screen.

2.3.3. FIREGUIDE Server

FIREGUIDE server (see Figure 2.16) includes the FIREGUIDE Listener, Smartprint Generation Module, FIREGUIDE databases, and AR and Shortest Path Route modules. *The server is divided into two phases, offline and runtime phases.* Database table population and Smartprint generation are performed in the offline phase. Shortest Route and Augmented Reality Modules work in the runtime phase, responding to the requests sent by firefighters. Next, we explain each module:

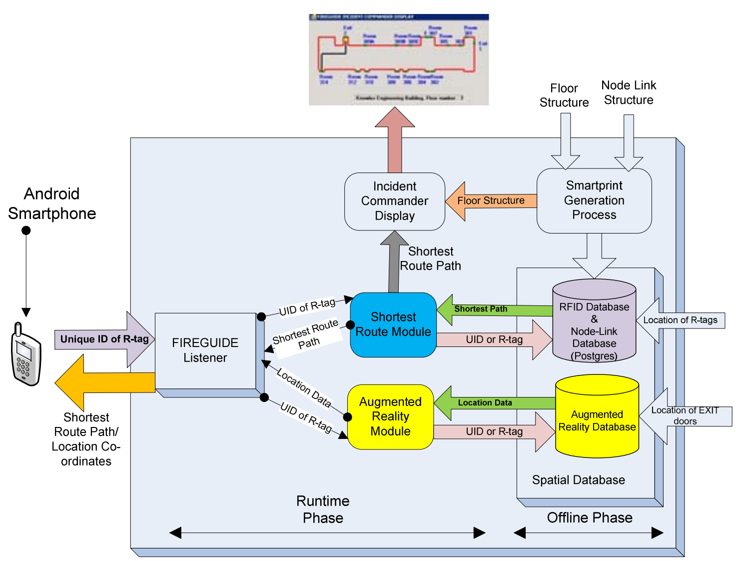


Fig.2.16. FIREGUIDE Server Architecture

In the following section, individual blocks have been explained in detail:

2.3.3.1. FIREGUIDE Listener

FIREGUIDE Listener keeps listening on a specific port for incoming requests from the firefighters. When the firefighter sends the shortest path route or augmented reality request, the appropriate module is chosen to serve the request. Once the shortest path or augmented reality module process the request, the response is conveyed back to the FIREGUIDE Listener to forward it to the Firefighter's Android Smartphone.

2.3.3.2. Smartprint Generation Module

Smartprint is an electronic blueprint of the building. Smartprint generation process is carried out in the offline phase. Floor structure variables (Smartprint details) include the dimensions of rooms and walls and corresponding floor number. When the first user request is received, all the required floor structure variables are stored in a local data structure (Hash Map and Linked Lists). *This is required to avoid large time delay of contacting database, when the next user request is received.* Floor structure variables are designed taking into consideration that route will not go through a wall.

2.3.3.3. FIREGUIDE databases

RFID Database stores the locations of all R-tags deployed in a building. Each location of an R-tag is assigned a node id. The schema for the RFID database is shown in Table 2.1.

UID	Source Node	Destination Node	Floor No.

Table.2.1. FIREGUIDE RFID database Schema

UID indicates the unique id of a passive R-tag. Source and destination ids represent the node id of an R-tag and the nearest Exit door node id respectively. Floor number column specifies the floor number on which the R-tag is located.

Due to special capabilities of a Spatial Database to store points, lines and polygons, it is possible to use it to store spatial relationship among various links joining different Room numbers on a building floor.

Quantum GIS [5] is used for drawing various links (linestrings) connecting source vertex to destination vertex (i.e. two different rooms on the floor) in the offline phase. Links are represented by a Spatial Geometry object called 'linestrings'. When a link is drawn to join two rooms or a corridor and a room, it will be given various attribute values such as: Source ID, Target ID and Link length (weight). Link weight indicates the distance between the source ID and target ID. e.g. if the source ID 'X' represents Room 312 and the target ID 'Y' represents the corridor, then the length (weight) between X and Y will indicate the distance of Room 312 from the corridor.

Source ID signifies the starting node for the link while the target id specifies the end node for a given link. The length parameter tells the normalized length for the given link relative to other links.

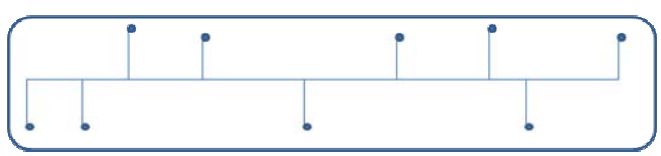


Figure 2.17 Link Structure

Once the link structure shown in Figure 2.17 is drawn in Quantum GIS along with the correct attribute values, we can transfer an entire link structure to a

Spatial Database Postgres [4] (installed with POSTGIS [6] extensions) with all its attribute values.

The advantage of this approach is that we can send queries to the Spatial Database to return required linestrings out of all other linestrings in the link structure. This simplifies the visual representation process significantly by showing shortest paths to the firefighters.

Node link structure schema

Length	Source ID	Target ID	Geometry Type

Table.2.2. FIREGUIDE Node-link structure schema

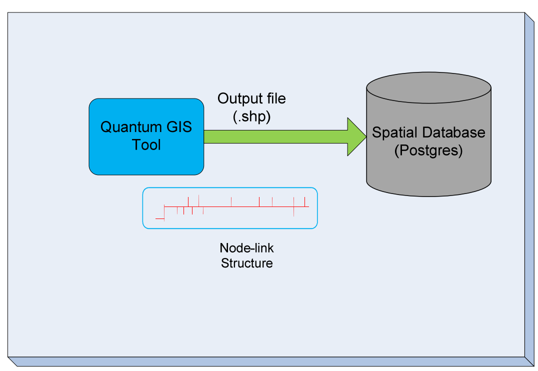


Fig.2.18. Populating Postgres with node-link structure

Augmented Reality database (Table 2.3) stores the same UIDs of R-tags as stored in the RFID database but it contains x and y co-ordinates of each R-tag (instead of source and destination node IDs) deployed in the building.

UID	X Co-ordinate	Y Co-ordinate	Floor number

Table.2.3. Augmented Reality Database

2.3.3.4. Shortest Route Module

Shortest route module is responsible for calculating the shortest route from the user location to the nearest exit door. When a firefighter scans a passive RFID tag, unique ID of the tag acts as an input for the shortest route module. It then fetches the source and target node id from the RFID database table and executes dijkshtra's shortest path query on the node-link database table (Table 2.2). There is no grid developed to avoid obstacles.

The shortest path query sent to the Spatial Database is:

dijkstra_sp('outline1',source ,target)

In the above query, *outline1* is the Database table which contains the node-link structure. *Source* is the starting node and *target* is the end node for the shortest route which is to be found. The Spatial database executes the above query by generating a new table which contains a shortest route calculation between given two points (source and target). The shortest path is returned in the form of a table which includes node ids to be traversed in order to reach the nearest EXIT door.

Once the shortest path is determined, it is sent to the Incident Commander Display module to overlay it on top of the Smartprint (see Figure 2.19) and to the Android Smartphone for the firefighter to view it (see Figure 2.4 (C)).

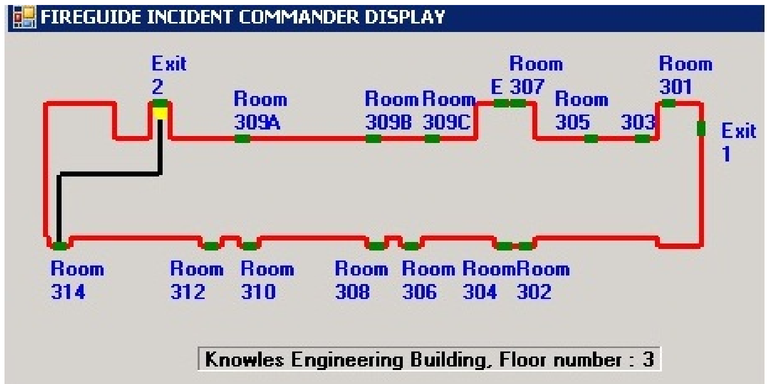


Fig.2.19. Incident Commander GUI

2.3.3.5. Augmented Reality Module

R-tag coordinates are stored in the Augmented Reality database in the offline phase. The Augmented Reality module (Fig. 2.20) at the server receives the unique ID of the R-tag as input and responds with x and y co-ordinates of the corresponding R-tag. All the Augmented Reality geometry calculations are performed at the Android Smartphone.

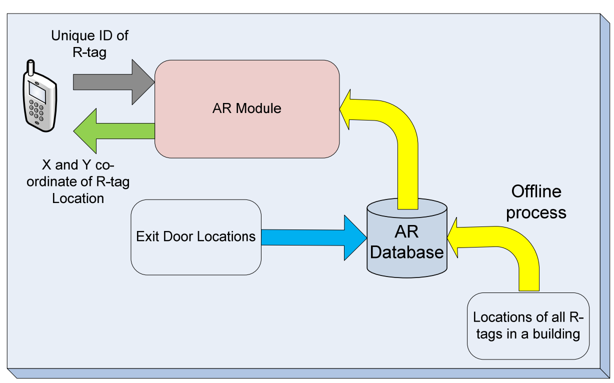


Fig.2.20. AR Module

2.4 Results

We are using java to develop the Android based client software and C# for the server application. PostgreSQL database with PostGIS libraries is used to answer all spatial queries. To avoid the cost of a cellular data plan, in our prototype we have used a Wi-Fi connection between the Android Smartphone and the server. In a real environment a cellular data connection must be used.

We deployed the system on the 3^{rd} floor of the Knowles Engineering building (see Figure 2.19). There are two exit doors on this floor and the overall length of the corridor is approximately 160 feet. The R-tags are deployed at every door. The user carries a RFID glove and an Android Smartphone enabled with the Bluetooth and Wi-Fi/Cellular.

Test correctness of navigation instructions: The user walks to each and every door and reads the R-tag located at that door. The shortest route for the user to reach to the nearest Exit door was displayed on the Android phone. In all cases the displayed shortest path route was correct.

Test correctness of Augmented Reality: The user walks in the corridor of the 3^{rd} floor of the Knowles Engineering Building and scans a random R-tag along his way. The Android phone displays the EXIT door directions with the distance information on top of a live camera feed (see Figure 1.1). As the user changes his orientation, EXIT doors direction information also adjusts itself to guide the user in the correct direction to reach the EXIT doors. We found that at few locations, the external magnetic field (due to electric wires and transformers) present on the 3rd floor of the Knowles Engineering Building interfered with the electronic compass of the Android platform resulting in an incorrect output. Apart from that, the user was able to follow the directions displayed on the camera feed successfully.

2.5 Hypothetical Scenario

We present a sample scenario to explain the flow of events in the system. R-tags are assumed to be deployed at appropriate locations on the 3rd floor of the Knowles Engineering Building (Testbed). Figure 2.19 shows the schematic of the testbed and specifications are mentioned in the section 2.4.

John is a firefighter and has adequate experience in rescuing victims. There is an emergency fire situation in the Knowles Engineering Building. John gets a call to rescue victims at this location. John takes a fire department vehicle and reaches the venue along with the other firefighters. The Incident Commander gives instructions to all firefighters to rescue victims.

John reaches the 3rd floor of the KEB and starts searching for the victims in every room. After finding a victim in Room 314, John activates the corresponding R-tag deployed in the corridor by placing his palm on top of the RFID tag at the Room 314. This generates a map of the closest path (Fig. 2.4 (C)) that John should follow to reach to the closest EXIT on the 3rd floor of the KEB. Upon seeing a newly generated map at the server, the Incident Commander gives directions to John using his walkie-talkie. John can also see the required route on his Android Smartphone in case he gets confused. As John moves through the building, the map displayed on his Smartphone is adjusted (rotated) to match his orientation inside the corridor.

If reaching to the closest EXIT door is infeasible due to the fire, John will press a button to switch to the Augmented Reality application (Fig. 1.1). This way, he will be able to view the other EXIT door location and the directions to reach each of them. John follows the directions shown in the Augmented Reality application to reach the other EXIT door.

John safely emerges out of the 3rd floor of the KEB along with the victim following instructions given by the Incident Commander and by following the shortest route map displayed on his Smartphone.

CHAPTER 3

INSIGHT SYSTEM

In this chapter, we present the INSIGHT system in detail. Section 3.1 provides information about the background work done in the field of indoor navigation systems developed for the blind or visually impaired users. Section 3.2 explains the system architecture in detail. System Testing and hypothetical scenario are described in sections 3.3 and 3.4.

3.1 Literature Survey

There has been considerable research to provide navigation information to the blind and visually-impaired users both indoors and outdoors [7-13]. While most of these systems cover a wide range of functions, the end devices are inconvenient for daily use because they are heavy and complex [7, 8, 10-13] or are robot-assisted [9], which is not a feasible option for a majority of the users.

Ali and Nordin [10] developed a system that identifies the surroundings of a blind person using a camera attached to their cane. A camera attached to the cane captures all scenes in front of it and features of these scenes will be compared with a database. The scene having the maximum matching feature is selected as a correct scene and Dijkstra’s shortest path algorithm is run to find the optimal path to reach the destination from the current node. The journey of a blind person consists of multiple sessions and in each session scene matching procedure is carried out to guide a blind person towards his destination. The procedure to search for the best path to reach the destination is linear which accounts for a considerable amount of time. Thus, the proposed system has the disadvantages of requiring retrofitting of an existing aid for the blind (creating a great deal of retraining) along and a high response time.

Bourbakis [11] introduces a system that combines outputs from cameras and range sensors (laser beams) to represent the 3-D space surrounding a blind person equipping them with a microphone, camera, range sensors and earphone. The paper raises concerns about the battery life of 2-D vibrational arrays as well as replacing the laser sensors by other less dangerous sensors.

Fallah [12] developed the AudioNav system which uses dead reckoning techniques for indoor localization over a 3-D map of the building. Dead reckoning is a technique which uses the previous position of user to estimate current position. If the previous position contains error, then this error will be propagated to future estimation of new positions. Thus, the error keeps accumulating as the number of readings increase leading to the high localization errors.

Chumkamon et al. [13] use RFID technology embedded in the floor along with a RFID antenna built-in a cane. The authors report the large response time to the client which is dominated by the communication delay with the server through a GPRS cellular network.

We introduce the INSIGHT system that provides enhanced perception of the indoor environment using passive RFIDs deployed in the environment, a custom-designed handheld unit which serves as the INSIGHT client device and the INSIGHT server that generates and stores the building information and the RFID tags deployment. INSIGHT is different from the other systems in the following aspects: 1) the user carries a custom made handheld unit with small form factor and an Android based phone, and 2) the system deployment and maintenance cost is very low due to the use of passive RFID tags.

3.2 INSIGHT System Architecture

INSIGHT system architecture depicted in figure 3.1 consists of the following system components-

1. R-tags - Passive RFID Tags deployed in the building
2. User device- RFID glove and an Android based Smartphone
3. INSIGHT Server – The software that stores the building layout and the R-tag deployment, communicates with the client and generates the navigation instructions.

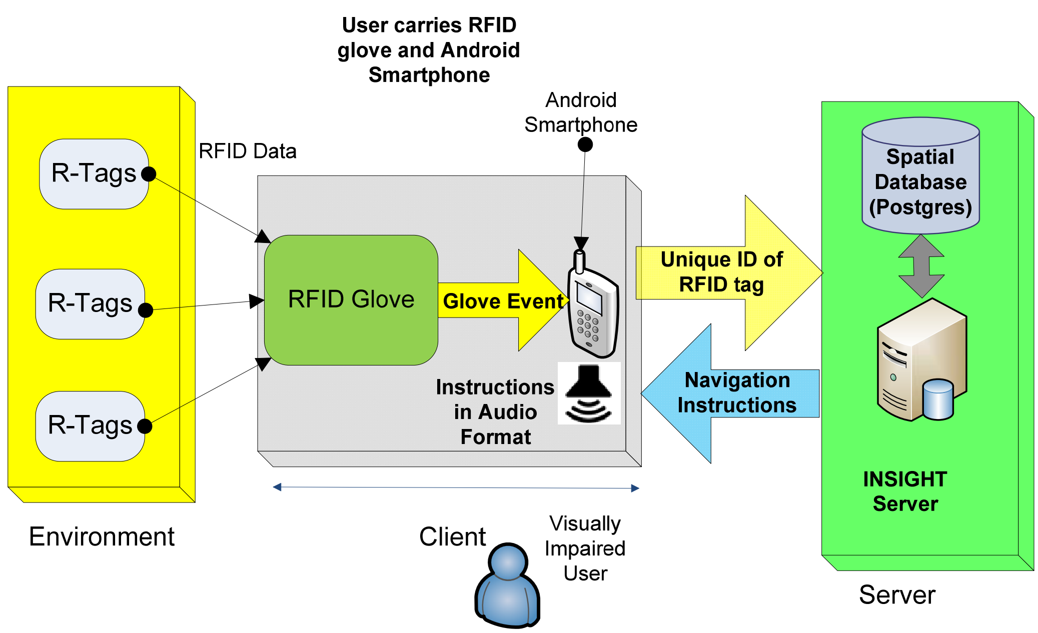


Fig.3.1 INSIGHT System Architecture

3.2.1 Environment

3.2.1.1 R-tags

The environment includes passive RFID tags (R-tags) that are deployed on each door at 4 ft height. R-tags are also embedded in kiosks located at specific points of interest such as the entrances/exits to a building, at the elevators, and at emergency exits. Reasons for selecting passive RFID tag (R-tag) over active RFID tags are explained in the FIREGUIDE Section 2.3. Along with the room numbers on each R-tag deployed in the building, it will also contain brail equivalent of the corresponding room number.

3.2.1.2 Kiosks

Kiosks are the junctions at which user's intention can be conveyed to the system. Kiosks are located at key points such as entrances of the building, elevators and emergency exits on each floor. Kiosks contain R-tags that represent floor numbers and/or locations (Rooms) in the building. By activating a specific R-tag, the user implicitly requests the navigation instructions to reach this destination (either a specific floor or a specific room number).

Fig 3.2 depicts the structure of the kiosk located at the entrance of the building (1st Floor). This kiosk contains separate R-tags for the 2nd and 3rd floor as shown. If the user wants to go to any room situated on the 2nd or 3rd floor, he will have to activate the R-tag that represents the 2nd or 3rd floor. Other R-tags represent rooms located on the 1st floor. E.g. if the user wants to reach Room 102, then he will have to activate the R-tag for Room 102 (see Fig 3.2). R-tags are placed above raised boxes to avoid accidental activation of the incorrect R-tag. Kiosks also provide special R-tags for the user to go to the Emergency Exit (denoted by X), Men's and Women's Restroom (denoted by M and W). A brail equivalent of the floor or room number is also written at the bottom of each R-tag.

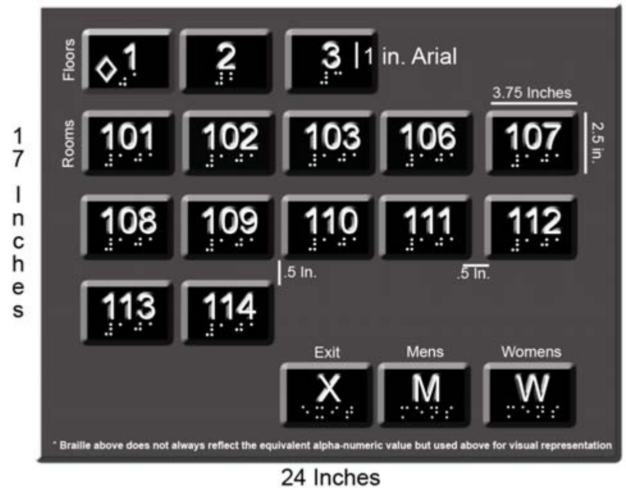


Fig.3.2 . Kiosk Structure

3.2.2. INSIGHT Client Module

The user carries a RFID glove and an Android based Smartphone.

3.2.2.1 RFID Glove

RFID glove system includes an Arduino Microcontroller, RFID Reader, Antenna, Bluetooth chip, a set of buttons, Rechargeable Battery, and a Power Regulator. The Arduino microcontroller is used to keep track of all the events occurring during the interaction between the user wearing the RFID glove and the environment. On scanning the R-tag, the RFID reader sends the R-tag data to the Arduino microcontroller. The Bluetooth chip is used to exchange data between the microcontroller and the Android Smartphone. The buttons on the RFID glove (Fig. 3.3) provide users different options to interact with the INSIGHT system. Each of the buttons has a unique texture and can be identified through touch.

Figure 3.3.RFID Glove (back view) Scanning an R-Tag

The buttons represent different functionality such as:

2.A Help button (denoted by H): Help button is used to guide the user back to the elevator after he reaches his destination. In other words, this button is used for return journey.

2.B Replay / Rewind button (denoted by R): Replay or rewind button is used to repeat previous instructions in case the user forgets them. If user presses replay button twice, the user will be able to hear previous to previous instruction.

2.C Instruction button (denoted by I): INSIGHT system makes sure that the user will not be given very long instructions to reach the destination. For all long navigation instructions, INSIGHT server inserts a special character ('&') at a place where instruction needs to be divided into 2 instructions. After receiving every instruction, the android client checks for the presence of a special character ('&'). If it is present, then instruction is divided into 2 parts and second part is stored locally on the android client. After the user follows the first set of instructions, he will press the Instruction button to get the next part of the instruction. In the absence of a special character, the android smartphone will not divide an incoming instruction and give it directly to the user in an audio form.

3.2.2.2 Android Smartphone Software

This section describes the client software which includes the Bluetooth and Wi-Fi modules, INSIGHT Application and the Text to Speech engine for audio output to user. The client software architecture is shown in fig 3.4.

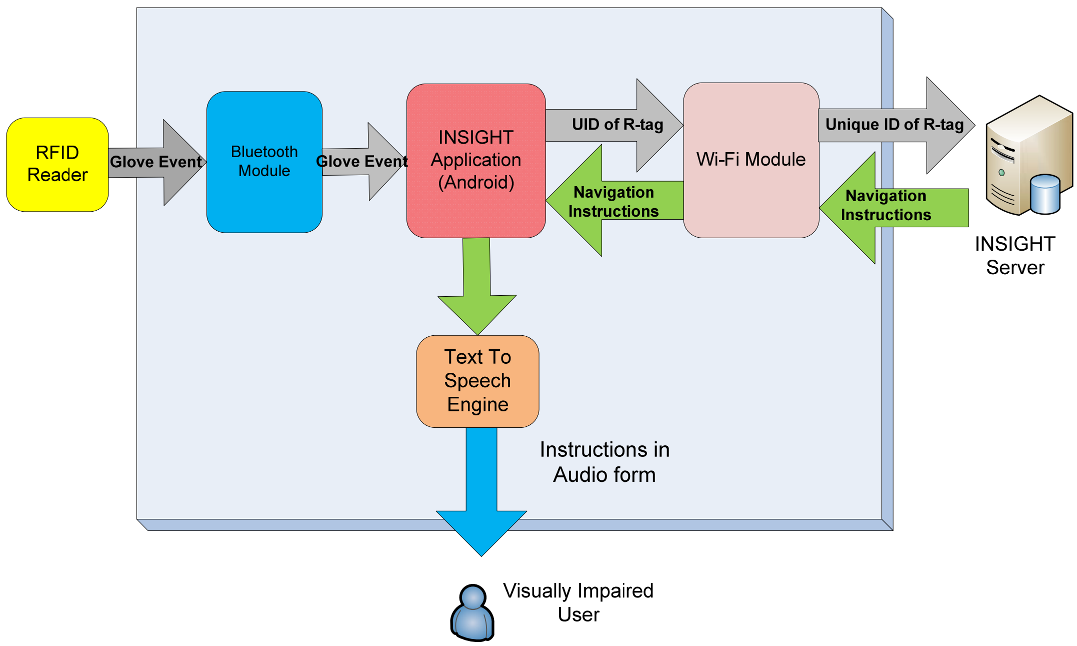


Figure 3.4 INSIGHT Client Architecture

The description of various components of the system is as follows:

3.2.2.2.1 Bluetooth and Wi-Fi modules

These modules in the INSIGHT system work similar to the Bluetooth and Wi-Fi modules described in the FIREGUIDE system (section 2.3)

3.2.2.2.2 INSIGHT Main Application

INSIGHT Application will differentiate among various events i.e. R-tag Scan Event, Help Button Press Event, Replay Button Press Event and Instruction Button Press Event. For R-tag Scan and Help Button Press events, Unique Identifier of the R-tag is sent to the INSIGHT Server over the Wi-Fi connection. Other events are processed locally and the output is converted into an audio form using the Text to Speech Engine. INSIGHT application block diagram is shown in fig. 3.5

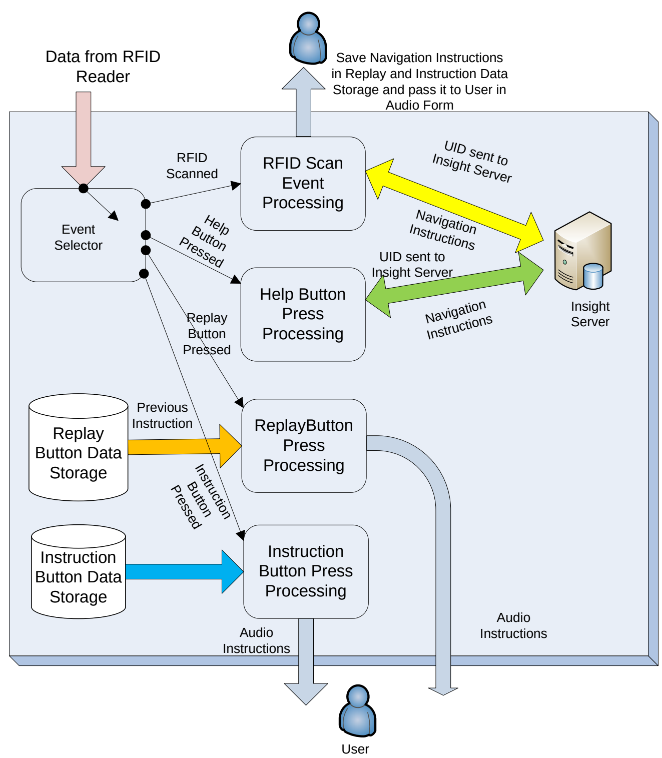


Fig.3.5. INSIGHT Main Application

3.2.2.2.3 Text To Speech Engine

INSIGHT System is designed to assist the blind or Visually Impaired people inside an indoor environment, so feedback given to the user needs to be in an audio or any other non-visual form. Android Smartphone provides an inbuilt Text To Speech (TTS) engine to convert textual information into an audio form.

3.2.3. INSIGHT Server

INSIGHT Server (Fig. 3.6) consists of the INSIGHT Listener, Shortest Path Generator, and Navigation module to give navigation instructions to the visually impaired people. It deploys Spatial Database (Postgres) to store the spatial relationships among all the rooms in the building. It is a multithreaded server supporting multiple clients, storing information about each session of the user.

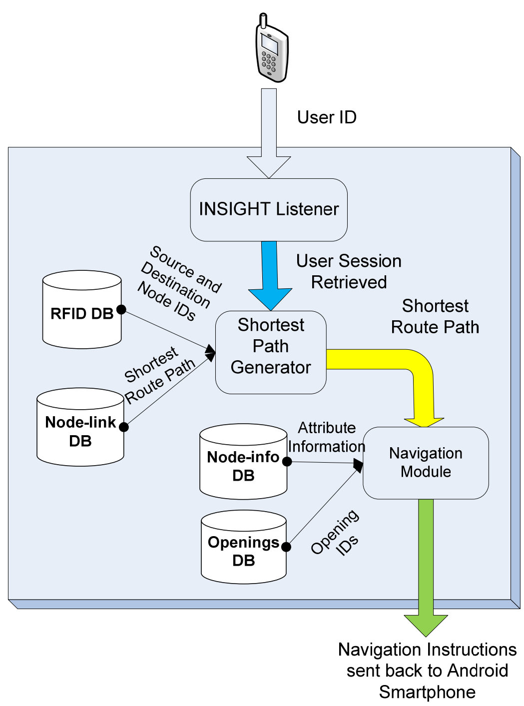


Figure. 3.6 INSIGHT Server Architecture

Components of the INSIGHT Server are:

3.2.3.1 INSIGHT Listener

INSIGHT Listener (Fig. 3.7) keeps listening for the user requests all the time. On receiving a user request, a check is performed to determine if the user is sending navigation instruction request for the first time. If the user already exists, then all the information about this user is retrieved from the previously stored session. Otherwise, a new session is created for the user. Once above check is finished, a new thread is fired to fetch Unique ID (UID) of the R-tag from the user.

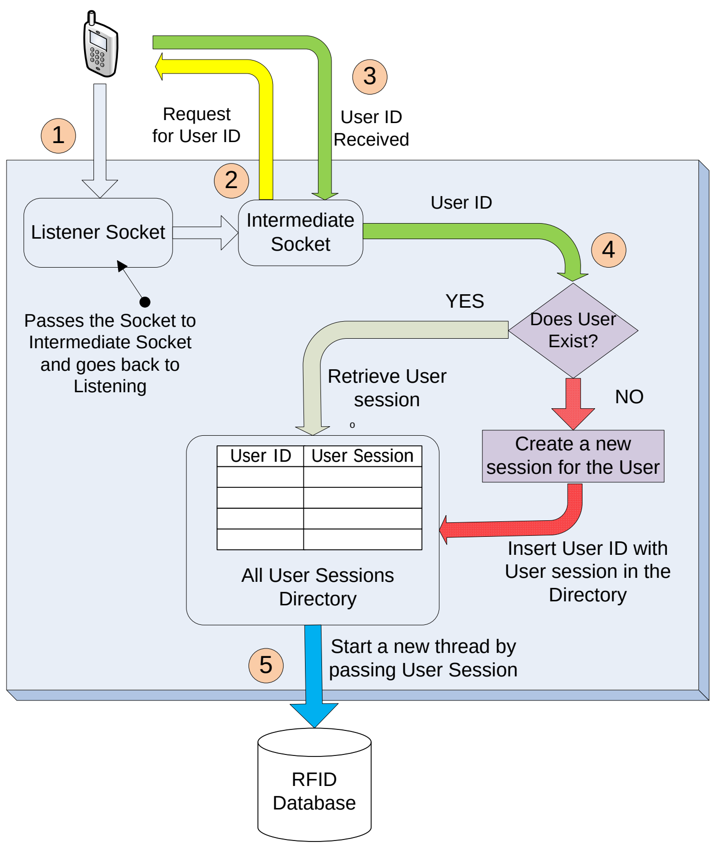


Fig. 3.7 INSIGHT Listener

3.2.3.2 Shortest Path Generator

Shortest Path Generator (fig. 3.8) interacts with RFID database and node-link database tables (Spatial Database, Postgres) to find out the shortest path between the source and destination node. Unique Identifier (UID) of the RFID tag scanned by the user, acts as an input for the Shortest Path Generator Module. The output of the Shortest Path Generator module is the database table containing node IDs which constitute the shortest route path.

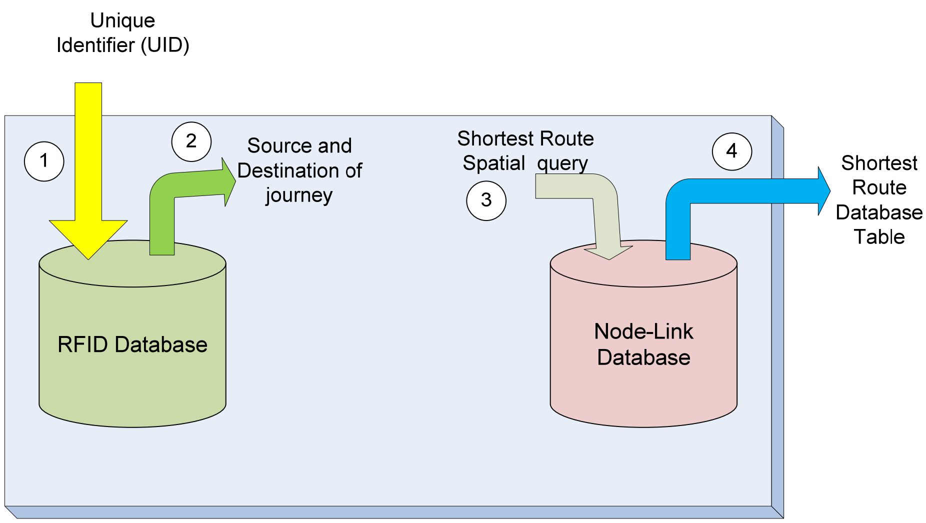


Fig 3.8 Shortest Path Generator

3.2.3.2.1 RFID Database Table

RFID database table (Table 3.1) contains all the information such as source, destination room number, etc about each and every tag deployed in the building.

UID	Source	Destination	Floor	Destination Floor	Return Destination

Table.3.1. INSIGHT RFID database schema

In the above table, UID represents the unique identifier of each RFID tag deployed inside a building. Source and destination indicate the start and end location of the user on scanning the corresponding RFID tag. Floor and

Destination Floor columns denote floor numbers. If the user wants to go to the 3rd floor from the 1st floor, destination floor ID will be 3 and the floor id will be 1. Return Destination column is mainly useful for the return journey of the user from a specific Room.

RFID database table is populated before the INSIGHT system is made available for use. On finding a match for the received UID from the user, corresponding source and destination are recorded to calculate the shortest route path between them.

3.2.3.2.2. Building Blueprint (Node Link Database, Postgres)

Building blueprint contains individual blueprints of each floor of the building. Once source, destination locations, and floor number are obtained from RFID database table, corresponding floor blueprint is referenced to find the shortest path between the source and destination point.

A spatial database is optimized to store and query data that is related to the objects in space. While typical databases can understand various numeric and character types of data, additional functionality needs to be added to databases to process spatial data types. These are typically called geometry or feature. In addition to the typical SQL queries such as SELECT statements, spatial databases can perform a wide variety of spatial operations like spatial measurements.

Population of Spatial Database (node-link structure) is similar to that explained in the FIREGUIDE section. The main difference between the node-link structure of the FIREGUIDE and INSIGHT systems is that in the INSIGHT system, user can not walk in the middle of the corridor thus the node-link structure has to be along the walls of the corridor. Also, in the INSIGHT system, node-link structure needs to take into account the reverse length of the link. The node-link structure of floor 3 of the Knowles Engineering Building (constructed in QGIS) is shown in fig.3.9.

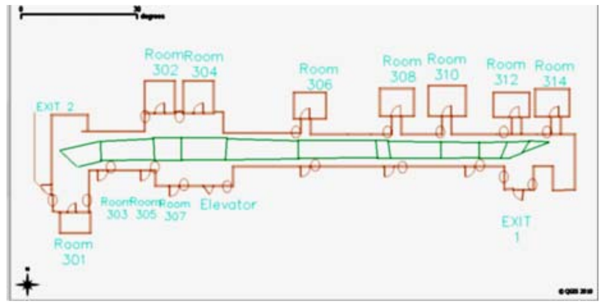


Figure 3.9. Floor 3 shape file

The schema of floor blueprint (Node-link Database) is as follows:

Id	Source	Target	Length	Reverse Length	Geometry

Table.3.2. Node-Link Database schema

In the above schema, *source* and *target* represent the source and destination points of the user journey. '*Length*' and '*Reverse Length*' columns indicate the weight of each link in both the directions. These values are useful for calculating cost of the end to end journey. The route (set of links) with lowest cost is declared as the shortest path between Source and Target.

The process of finding the shortest route path between 2 nodes is similar to that explained in the shortest route module in the FIREGUIDE server section (section 2.3)

Consider a sample layout as shown in Fig 3.10.

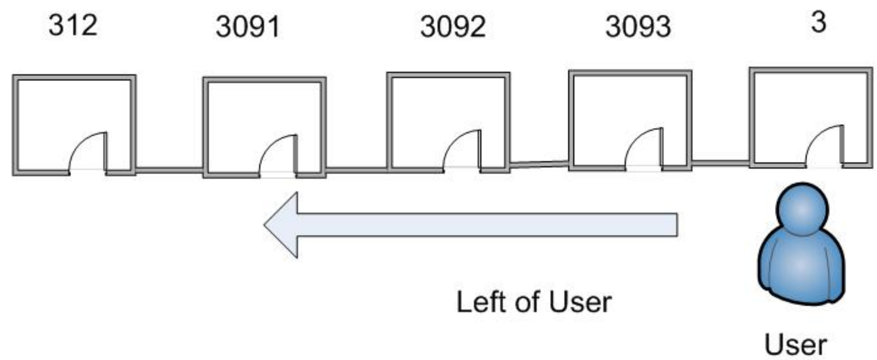


Fig. 3.10 Sample Layout

E.g. The shortest path between node id=3 and node id=312, is given as follows:

3
3093
3092
3091
312

Table.3.3. Shortest Route path Table

Thus in order to reach node 312 (Room 312), the user will have to traverse a route as shown in the table 3.3.

3.2.3.3. Navigation Module

Navigation Module (Fig. 3.11) formulates navigation instructions after receiving the shortest route path from the Shortest Path Generator Module (Postgres database). It accesses node_info database table to acquire the information about each and every node in the shortest path route.

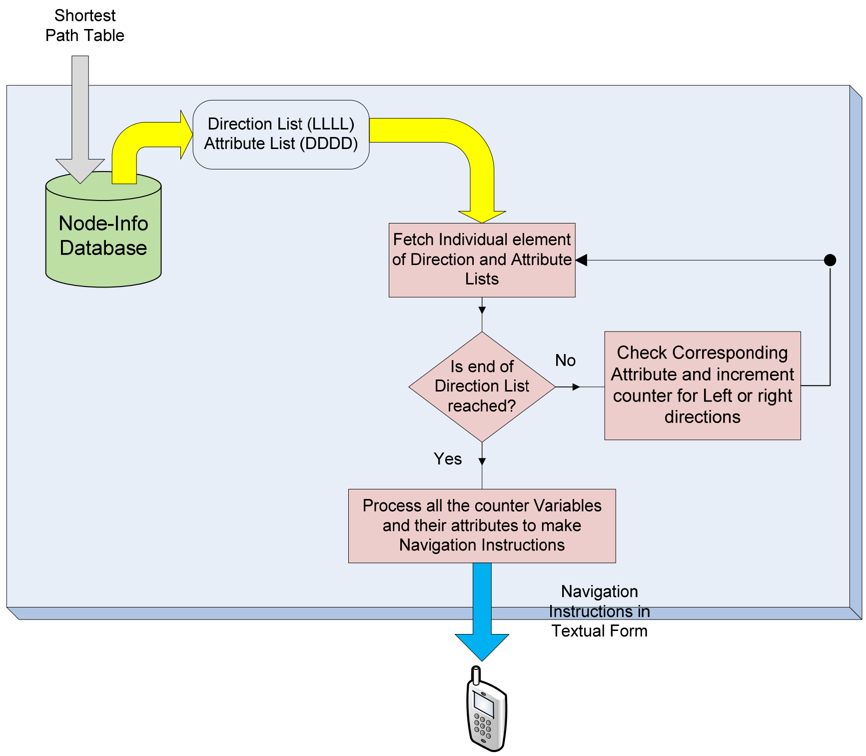


Fig. 3.11. Navigation Module

'Node_info' table has following schema-

Node ID	Left Node ID	Right Node ID	Opposite Node ID	Attribute	Description	Floor ID

Table.3.4. Node Info Database schema

Every room in the building is represented by a Node ID. The 'id' represents the node id. Left_id, right_id and opp_id columns contain node ids on left, right and opposite of current Node. Attribute column indicates whether given Node is a door, opening, Elevator or Exit door. Last column gives the floor number of the node. The other database table called *openings*, associates every door inside an opening to a unique *opening id*.

Possible attribute values in the system are:

Regular Room – Attribute – ‘D’

Opening – Attribute – ‘DO’

Elevator – Attribute – ‘E’

Exit doors – Attribute – ‘EX’

The navigation instructions are formed by correlating each node in the shortest path table to the *node_info* and *openings* database tables. E.g. if the user wants to go from node 3 to node 312 in the layout shown in fig. 3.10, then he will have to proceed towards his left (assuming the user is facing towards the Door with Node id = 3) for 4 number of doors to reach node 312 (Room 312).

The direction List would be “LLLL” (See fig. 3.12), where each L represents left direction. The other conventions used by the navigation module are O and R, indicating opposite and Right directions respectively.

After direction List is formed, next job is to check if there are any openings, elevator or regular rooms along the journey. The attribute List (Fig. 3.12) is formed by parsing the attributes of corresponding nodes in the shortest route table. Attributes can be obtained by looking into the *node_info* database table.

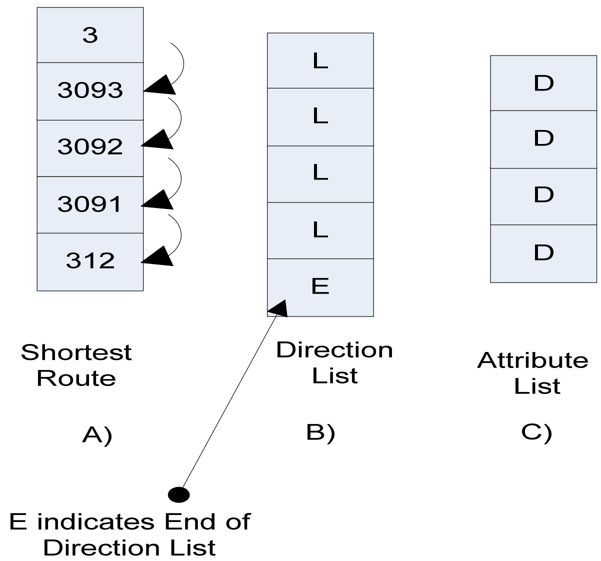


Fig. 3.12. Shortest Route Path Processing

In the above example, assuming all nodes lying between 3 and 312 are regular doors, instruction given to the user would be: "Please turn Left and proceed along your right side wall for 4 doors and then you will reach at Room 312".

The above instruction will be sent to the Android client.

3.3 INSIGHT System Testing

The testing that was performed in the Knowles Engineering Building by the technical team as well as the Mobility and Orientation instructor tested the following features of the INSIGHT system:

1. *Testing the correctness and robustness of the navigation instructions,* on all the 3 floors of the building independently, and for inter-floor navigation. INSIGHT system navigation instruction accuracy was tested by choosing

different source and destination locations on the same floor as well as on different floors of the building. Both intra and inter floor navigation instructions were consistent and correct.

2. *Testing the reliability and availability of the system even when users use the system in unintended ways.* The user will be interacting with the glove throughout his entire journey and because of his visual impairment, buttons could be accidently pressed as well as R-tags accidently scanned. The system must handle these interactions to ensure the user's destination is not lost or altered. In order to test for these situations we prepared a list of possible interactions with expected results. The list includes events such as pressing of Help button before reaching destination, scanning R-tag at the door instead of kiosk to select the destination location, scanning R-tag instead of pressing Help button after reaching the destination and INSIGHT server receiving invalid Unique ID of R-tag. Each one of these situations was then tested in the Knowles Engineering Building to ensure that the INSIGHT system provides reliable instructions.

3. *Testing system usability of the navigation instructions*, i.e., the instructions clarity (i.e., compliance with mobility and orientation instructions that are currently given to the blind and visually impaired) and pace (e.g. number of instructions given at a given time). The speed and the amount of information that needs to be given at a time are very important factors to guide the visually impaired people towards their destination. This phase was thoroughly tested by the Mobility and Orientation instructor for the blind and visually impaired.

4. *Flexibility and Control over the user journey*-INSIGHT system was tested to verify the kind of control it should have over the route taken by the user.

Due to the use of spatial database, INSIGHT system was able to navigate the user via a route which is easy to follow. This was important because, sometimes the shortest route will have too many complexities (many corners and obstacles) for the blind or visually impaired user to undertake. In this scenario, the user can reach his destination quickly by following a bit longer but straight-forward route. This phase was thoroughly tested by the Mobility and Orientation instructor for the blind and visually impaired.

3.4 Hypothetical Scenario

We present a sample scenario to explain the flow of events.

John is a freshman and majoring in Computer Systems Engineering. He is trained by the mobility and orientation instructor on the use of the INSIGHT system. He stays in the Knowlton Dormitory and wants to meet his advisor to discuss the courses he needs to take. His advisor's office is on the 3rd floor (room number 312) in the Knowles Engineering Building. He calls campus Disability Services Office for the ride to Knowles Engineering Building. John has a cane as well as a RFID glove and an Android based phone. It is assumed that John knows the destination room and floor numbers. Here is John's journey:

1. *Designated Drop off Point*: Every building on campus has a designated drop off point. Campus Disability Services van drops John at the Designated Entrance point (Exit 1 in Figure 3.13). Once he reaches the Exit 1, he moves towards the Kiosk located at the Exit 1.

2. *Kiosk at the Entrance:* The Kiosk at Exit 1 (see Figure 3.2) includes R-tags for every room on the 1st floor and one R-tag for the other floors. John finds the R-tag that represents the 3rd floor using his finger and then uses his palm to scan the R-tag. He gets the following directions to reach the Elevator on the 1st floor: 'Your Destination is on floor number 3, To reach your destination, Please turn right and proceed along your left side wall until you have reached one opening, Enter this opening. Once you reach there, please scan the card located on the Door'.

Route: (Exit 1 > Room 102 > Room 107 > Elevator)

3. *Kiosk at the Elevator on 1st floor:* Once John reaches at the elevator kiosk (see Figure 3.2), he will scan the R-tag that belongs to the 3rd floor. Here he will get audio instructions informing him that he has reached the Elevator and he should proceed to 3rd floor (destination floor) using this elevator. John gets the following instructions: '*You have reached at the Elevator of Floor number 1, Please use Elevator to proceed to Floor number 3. When you exit the elevator at Floor number 3, turn around and face elevator, the kiosk will be located to your immediate left*'.

4. *Kiosk at the Elevator on 3rd floor:* After John reaches the 3rd floor using the elevator (see Figure 3.14), he will find another kiosk on his right side as soon as he comes out of the elevator. Here, John will have to activate the R-tag that represents his destination room number i.e. 312. Once he scans the desired destination R-tag with the RFID glove, John gets the following directions to reach his destination room number (312): *'Your destination is Room 312, To reach your*

destination, Please turn Left and proceed along your Right side wall for 3 doors, Once you reach there, Scan the card located at the door'.

Route: Elevator > Room 309 C > Room 309 B > Room 309 A > Room 312

5. *Any R-tag leads towards the destination*: In case John scans any R-tag on the floor he will be given directions to the chosen destination. For example, if John scans the R-tag at Room 306, he will get the following instructions: *Please turn right and proceed along your left side wall until you have reached the* 3^{rd} *opening, Enter this opening and you will reach Room 312".*

6. *Return journey:* After John finishes the meeting with his advisor he wants to obtain the return instructions. He presses the HELP button on the RFID glove. This will give him the following directions to reach the elevator on the 3^{rd} floor:

Your destination is Elevator, To reach your destination, Please put your back to the door and begin your return journey. Please proceed towards the opposite wall. After the user presses the instruction button, he will get following instructions: Please turn Right and proceed along your left side wall until you reach at the Elevator. Once you reach at the elevator, Please scan the card belonging to your next destination'.

7. *Kiosk at the elevator on* 3^{rd} *floor:* Once he reaches at the kiosk, he will scan the R-tag that corresponds to the 1^{st} floor. John gets following Instructions: *'You have reached at the Elevator of floor number 3, Please use elevator to*

proceed to Floor number 1. When you exit the elevator at Floor number 1, turn around and face elevator, the kiosk will be located to your immediate left'.

8. Kiosk at the elevator on 1st floor: After reaching at the elevator of floor number 1, John will scan the Emergency Exit card (denoted by X in Figure 3.2). As he scans this card, he will get the following instructions: '*Your destination is EXIT door, To reach your destination, Please turn around and proceed towards the opposite wall. After the user presses the instructions button, he gets the following instructions: Please turn Left and proceed along your right side wall until you reach 1st opening. Once you reach there, Please continue walking along the wall for 1 door and then you will reach at the Exit door. Always scan the card located at the kiosk on the Right side of the Exit door before exiting the Floor number 1.*'

9. Kiosk at Exit 1: As John reaches at the kiosk located at Exit 1, he scans the Exit card (denoted by X), to convey to the system that he wants to leave the building. He gets the following instructions: '*You have reached at the Exit door on floor number 1, Please open the Exit door and walk straight to go out of the building.*'

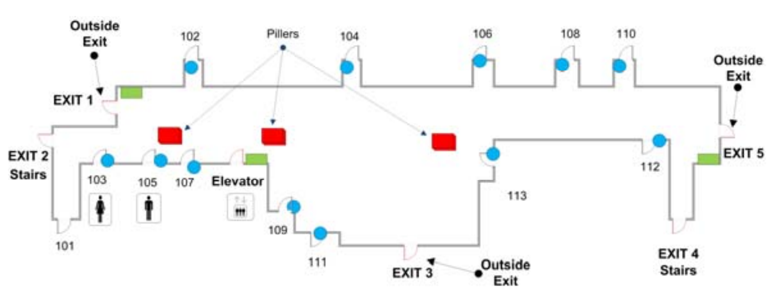


Figure 3.13. 1st Floor Structure of Knowles Engineering Building

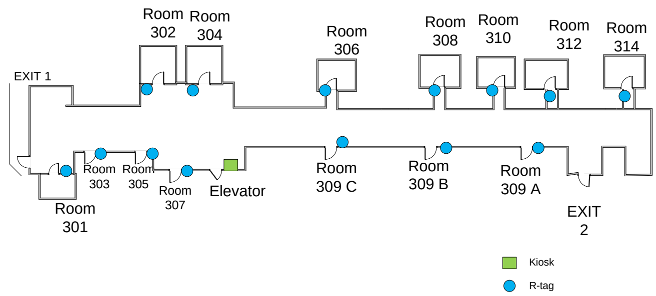


Figure 3.14. 3rd Floor Structure of Knowles Engineering Building

CHAPTER 4

FUTURE WORK

This section comprises of the possible future modifications to the FIREGUIDE and INSIGHT Systems.

4.1 FIREGUIDE System

1. Use temperature sensors to convey the current temperature of the area, where firefighter is located. Augmented Reality can be used to keep firefighter updated about the temperature of the building floor.
2. Improvement of the design of the RFID glove taking into account the actual firefighting gloves.
3. Employ a new technique of locating the user inside a building without being in the close proximity of the deployed sensors. This will help firefighter to navigate faster without scanning any R-tags.

4.2 INSIGHT System

1. Guide visually impaired people by keeping track of their orientation with respect to their destination Room number.
2. Obstacle avoidance can be added to the INSIGHT system to make the system more effective.
3. Integrate the RFID glove and the Android Smartphone into one device, making it more user-friendly.

CHAPTER 5

CONCLUSION

We introduced two novel systems, FIREGUIDE and INSIGHT that use RFID technology to provide indoor navigation for the firefighters and the blind. The FIREGUIDE system assists the rescue of firefighters inside a building and the INSIGHT system helps the blind or visually impaired people navigate independently inside a building.

FIREGUIDE system was able to successfully track the firefighter on a particular floor inside a building using the RFID Technology. The firefighter location and the shortest route between the firefighter’s current location and the nearest exit door were indicated in a GUI developed at both the server seen by the Incident Commander and client side observed by the firefighter. Augmented Reality prototype including Exit door objects along with their distance from the user were overlaid successfully on top of a live camera feed.

The INSIGHT system that we designed, implemented, deployed and tested in the Knowles Engineering Building includes the following advantages:

- INSIGHT system was able to successfully provide directions to reach the required destination through the Knowles Engineering Building
- INSIGHT environment, i.e. the Kiosks and R-Tags follow the ADA signage regulations [16] and provide a tactile feel and color contrast for the visually impaired users.

INSIGHT system is flexible enough to accommodate additions of new rooms or new structures in the building.

BIBLIOGRAPHY

[1] Lighthouse International Website: http://www.lighthouse.org/about/advocacy.htm

[2] Wilson J., Bhargava V., Redfem A., Wright P, “A wireless sensor network and incident command interface for urban firefighting”, Proceedings of the 4th Annual International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, MobiQuitous 2007

[3] http://www.i-a-i.com/view.asp?aid=105

[4] http://www.postgresql.org/

[5] http://www.qgis.org/

[6] http://postgis.refractions.net/

[7] D. Ross and B. Blasch, “Development of a Wearable Computer Orientation System”, In Personal and Ubiquitous Computing, 6:1, pp. 49-63, 2002.

[8] S. Willis, S. Helal, “RFID Information Grid for Blind Navigation and Wayfinding”, Proceedings of the 2005 Ninth IEEE International Symposium on Wearable Computers, 2005.

[9] V. Kulyukin *et al.* ” RFID in Robot-Assisted Indoor Navigation for the Visually-impaired”, Proceedings of the IEEE International Conference on Intelligent Robots and Systems, October 2004.

[10] A.M. Ali, M.J. Nordin, ”Indoor navigation to support the blind person using weighted topological map”, International Conference on Electrical Engineering and Informatics, 2009.

[11] N. Bourbakis, "Sensing Surrounding 3-D Space for Navigation of the Blind", IEEE Engineering in Medicine and Biology Magazine, Volume: 27 , Issue: 1 pp 49 – 55, Jan.- Feb. 2008.

[12] N. Fallah, "AudioNav: a mixed reality navigation system for individuals who are visually impaired", ACM SIGACCESS Accessibility and Computing, Issue 96, pp. 24- 27, January 2010.

[13] S. Chumkamon, P. Tuvaphanthaphiphat, P. Keeratiwintakorn, "A blind navigation system using RFID for indoor environments," 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology,. ECTI-CON 2008., vol.2, pp.765-768, May 2008.

[14] Carmine Ciavarella and Fabio Patern\&\#242;. 2004. The design of a handheld, location-aware guide for indoor environments. *Personal Ubiquitous Comput.* 8, 2 (May 2004), 82-91. DOI=10.1007/s00779-004-0265-z http://dx.doi.org/10.1007/s00779-004- 0265-z

[15] Dik Lun Lee and Qiuxia Chen. 2007. A model-based WiFi localization method. In Proceedings of the 2nd international conference on Scalable information systems (InfoScale '07). ICST (Institute for Computer Sciences, Social- Informatics and Telecommunications Engineering), ICST, Brussels, Belgium, Belgium, , Article 40 , 7 pages.

[16] http://www.fastsigns.com/getdoc/8fa278ea-21dc-4162-ab70-04c61fcd5736/ADA-Signage-Regulations

[17] Beginning OpenGL game programming, second edition, by luke benstead, Dave Astle and Kevin Hawkins

[18] OpenGL ES tutorial for Android- http://blog.jayway.com/2009/12/03/opengl-es-tutorial-for-android-part-i/

[19] http://developer.android.com/reference/android/view/View.html

[20] http://developer.android.com/reference/android/view/SurfaceView.html

[21] Spatial Augmented Reality by Oliver Bimber and Ramesh Raskar

[22] Siddhesh Gandhi, A. Ganz, G. Mullett, "FIREGUDE: Firefighter guide and tracker", IEEE EMBC Conference, Buenos Aires, Argentina, September 2010

[23] Aura Ganz, Siddhesh Gandhi, Carole Wilson and Gary Mullett, "INSIGHT: RFID and Bluetooth Enabled automated Space for the Blind and Visually Impaired" , IEEE EMBC Conference, Buenos Aires, Argentina, September 2010